

**A PROGRAM TO DETECT AND CHARACTERIZE
EXTRA-SOLAR GIANT PLANETS**

NASA Grant NAG5-10854

Annual Report

For the period 1 May 2001 to 30 April 2002

Principal Investigator

Robert W. Noyes

March 2002

Prepared for

National Aeronautics and Space Administration

Washington, D.C. 20546

Smithsonian Institution
Astrophysical Observatory
Cambridge, Massachusetts 02138

<p>The Smithsonian Astrophysical Observatory is a member of the Harvard-Smithsonian Center for Astrophysics</p>

The NASA Technical Officer for this Grant is Dr. Joseph M. Boyce, Code SR, NASA Headquarters, Washington, D.C. 20546

Progress Report for NASA Grant NAG5-10854,
“A Program to Detect and Characterize Extra-Solar Giant Planets”
Robert W. Noyes
March 15, 2002

This is a progress report for the first year (from 5/1/2001 to 4/30/2002) of the three-year Grant NAG5-10854.

Recent Progress

1. Improvement in Precise Radial Velocity (PRV) analysis code

We have improved the PRV analysis code used for the analysis of the AFOE observations. The new code includes a physically motivated analytic expression for the instrumental point spread function (PSF), including allowance for PSF asymmetry. The new code also incorporates improved minimization procedures to adjust all the model parameters. Both improvements lead to model (M) spectra that better matches the observed (O) spectra, down to the Poisson limit for our typical (SNR=100) observations (i.e., $RMS(M - O) \leq 1\%$). As a result our precision and stability has greatly improved: from 15-10 m/s down to 10-7 m/s, with no residual slow drift of the baseline.

2. Reanalysis of previous data

We have re-analyzed the last 7 years of AFOE observations with the new code, reprocessing over 8,000 spectra (with 97% of our objects reprocessed, and 84% fully validated); new observations are since routinely analyzed with the new version of the PRV code.

3. Improvements to the AFOE spectrograph.

We have obtained internal funds and are currently in the process of rebuilding the AFOE spectrograph in order to optimize its efficiency for planet detection and increase its throughput. The original configuration of the spectrograph allowed for use of either a ThAr reference or an I2 reference. The ThAr reference allowed use of a much broader spectral range, necessary for asteroseismology experiments. However, we have found that we were able to achieve better long term precision using the I2 absorption cell for planet detection, so we are replacing the gratings to allow us to record all of the spectral features in the I2 range (5000 to 6200 angstroms). At the same time, we are replacing the collimator and the camera optics to increase the throughput. Restricting the spectral range to 5000 to 6200 Å allows the use of transmission camera optics that are more efficient and have no obscuration.

We have already replaced the optical fibers and achieved a 30 to 50 % improvement in throughput due to better finishing of the fiber ends. We made use of the technology developed for polishing the MMT Hectochelle fibers. Replacing the fibers was made necessary due to the original fibers being damaged when the 60” telescope ran away, past its limits.

4. Development of PRV capabilities for the Hectochelle.

One goal of our proposed work is to develop the capability for making radial velocity measurements using the Hectochelle spectrograph at the 6.5-m MMT telescope. We have now manufactured the Iodine cells for this spectrograph. These cells had to be a special shape in order to allow their use with the 300 fibers of the Hectochelle. The Hectochelle is due to be installed this spring and we will be able to start using it for PRV work with the I2 cells soon thereafter. We can currently only use a single echelle order since we do not yet have a cross-disperser that would allow us to use the full I2 spectral range. However, a detailed design of a cross-disperser using stacked prisms has been carried out and ray-traced. We are currently proposing or planning to propose to both government (NSF and NASA) and private sources in order to get it funded.

5. Extra-solar planet studies

Despite our fiber problems and our work on upgrading the spectrograph, we have been able to identify several very promising exo-planet candidates. Probably the most interesting is that we have found a triple star system containing at least one, and possibly more than one planet. The planet orbits the primary star, but the inner stellar companion, a late M dwarf, is as close as 30 AU, so it may well have had some dynamical effect on the planetary orbit as well as the protoplanetary nebula. Fitting a single period to the data leaves large residuals in the data. The star is an F star so these residuals could be due to activity. We are having the star observed by the Mt. Wilson H-K program and by the photometric APT's to test this. We have also asked the group at Lick Observatory (Debra Fisher) to also observe this star and her results from last year are consistent with the AFOE results. The star has just become observable again and we will continue to monitor it to sort out its complicated story.

We have several other stars that show either long or short term variations in radial velocity that are likely to be planetary companions. They all have either rather small amplitude variations or long periods so additional observations are needed. We are also monitoring a K giant, HD3346, for which there is a known low mass companion. This companion was discovered by Mclure et al, 1985. Our data confirm that it has a 576 day period with an amplitude of about 600 m/s and so, if one assumes a stellar mass of about 1 solar mass, $M \sin i$ is about 22 Jupiter masses. There are large residuals to this fit, most likely due to pulsations, but there may be additional companions as well. Greg Henry has kindly obtained photometric data on this star while we made intensive radial velocity observations during the same time frame, and these combined data are now under analysis.

6. Longer-term plans for the AFOE.

We expect to upgrade the AFOE by this summer and to switch over from using it as a survey instrument to using it as a follow-up instrument to detections on the MMT. Because of the relatively low efficiency of the fiber-fed spectrograph and the relatively small telescope, the AFOE is no longer very competitive for surveying large number of stars for exo-planets. However, it should be very effective as a follow-up instrument to the MMT Hectochelle, for filling in orbits of probable companions.

7. Transiting Planets. We completed and published the analysis of HST spectrally-integrated STIS observations of the transiting gas-giant planet HD 209458 b, leading to a definitive determination of the planet's radius and orbital inclination, the radius of the star, and the stellar limb darkening parameter (Brown et al 2001). Useful upper limits were placed on the size of opaque planetary rings, and the size of any accompanying moons. A subsequent spectral analysis of the STIS data gave a clear detection of sodium in the planet's atmosphere, at a level consistent with predictions of models which incorporate either the presence of clouds high in the atmosphere, a low primordial abundance of sodium, or the reaction of atomic sodium into molecular gases or condensates (Charbonneau et al 2002).

8. Related Theoretical work.

We have studied the expected transmission spectrum of HD 209458b during transits (Brown et al 2001). In addition we used theoretical stellar evolution calculations to obtain a definitive description of the physical parameters of both planet and star (Cody and Sasselov 2002). We have also participated in a study of the metallicity signature of "pollution" of a stellar surface by infalling dust and planetesimals in the process of star and planet formation (Murray et al 2001).

References

- Brown, T. M., Charbonneau, D., Gilliland, R., Noyes, R., Burrows, A., 2001, "Hubble Space Telescope Time-Series Photometry of the Transiting Planet HD 209458", *Ap. J.* 552, 699.
- Charbonneau, D., Brown, T.M., Noyes, R. W., Gilliland, R. L., 2002, "Detection of an Extrasolar Planet Atmosphere", *Ap. J.* In Press.
- Cody, A. and Sasselov, D. 2002,"HD209458: "Physical Parameters of the Parent Star and the Transiting Planet", *Ap. J.* In Press
- Murray, N., Chaboyer, B., Arras, P., Hansen, B., and Noyes, R. 2001, "Stellar Pollution in the Solar Neighborhood", *Ap. J.* 555, 801.

